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# Description

# Method for Triggering an Action

## Cross Reference to Related Applications

[0001] The present application is a continuation-in-part of co-pending U.S. Patent Application Serial No. 10/710,790 filed on August 3, 2004, which is herein incorporated by reference. Said application, Serial No. 10/710,790 claims priority of co-pending U.S. Provisional Patent Application Serial No. 60/481,225 filed August 13, 2003, which is herein incorporated by reference.

## Federal Research Statement

[0002] This invention was made with government support under Contract No. DE-FC26-01NT41229 awarded by the U.S. Department of Energy. The government has certain rights in the invention.

## Background of Invention

[0003] The present invention relates to the field of triggering synchronized actions in downhole environments, such as along a drill string used in oil and gas exploration, or

along the casings used in production wells and other equipment used in oil and gas production.

[0004] Triggering a seismic source and simultaneously collecting data has been expressed for more than half a century. The precise relationship between the time the seismic source triggers and the time the seismic receivers collect data may be useful in determining subterranean formations and thereby improve oil, gas, and geothermal well exploration and production. For example, to determine the subterranean formations surrounding a well bore, it may be beneficial to record seismic data synchronously with the triggering of a seismic source. Also, it may be useful to trigger multiple seismic sources synchronously. Several methods and systems to take such measurements, and correlate the times of triggering two actions are known in the art. In the downhole environment, systems and methods have been developed that have direct communication by wire or through fluid to the downhole device, and trigger a downhole device according to instructions received via these methods.

[0005] One example of such systems is described in U.S. Pat. No. 6,624,759 to Tubel , et al., which discloses a communication system that enables communication from a surface

location to a downhole location where instructions communicated are executed. The system employs accelerometers to sense vibrations traveling within the annulus fluid or the tubing string. The accelerators provide signals representative of the vibration generated at the surface of the well to a microcontroller. The microcontroller is programmed to energize a nichrome element to actuate the downhole tool in response to a user-defined vibration sequence. The vibration sequence includes a defined number of vibration cycles. Each cycle includes alternating periods of vibration and no vibrations with each period lasting for a defined length of time. The user may program the parameters of the sequence and arm the vibration receiving unit on site through a handheld terminal that interfaces with the microcontroller.

[0006] Several systems for actuating or triggering downhole tools are described in U.S. Pat. Nos. 6,349,766; 5,558,153; and 4,471,435 and describe a variety of non-electrical methods to trigger a downhole tool. These methods include placing a chemical sensor downhole and introducing a chemical slug into fluids being pumped downhole, or using a burst of neutrons downhole to trigger a downhole tool.

[0007] U.S. Pat. No. 6,386,108 to Brooks, et al. discloses the initiation of one or more explosive devices. In response to activation of a trigger signal down the electrical cable, a switch coupling the energy source and an initiator is closed to couple the energy source to the initiator.

[0008] A system that may be used to trigger downhole actions is disclosed in U.S. Pat. No. 6,670,880 to Hall, et al. which discloses a system for transmitting data through a string of downhole components. In one aspect, the system includes first and second magnetically conductive, electrically insulating elements at both ends of the component. Each element includes a first U-shaped trough with a bottom, first and second sides and an opening between the two sides. An electrically conducting coil is located in each trough. An electrical conductor connects the coils in each component. In operation, a varying current applied to a first coil in one component generates a varying magnetic field in the first magnetically conductive, electrically insulating element, which varying magnetic field is conducted to and thereby produces a varying magnetic field in the second magnetically conductive, electrically insulating element of a connected component, which magnetic field thereby generates a varying electrical current in the sec-

ond coil in the connected component.

## SUMMARY OF INVENTION

[0009] A method for triggering an action of at least one downhole device on a downhole network integrated into a downhole tool string synchronized to an event comprises determining latency, sending a latency adjusted signal, and performing the action. The latency is determined between a control device and the at least one downhole device. The latency adjusted signal is sent to the downhole device for triggering an action. The action is performed downhole synchronized to the event. Disclosed is a method for determining latency consisting of the steps: a control device sends a signal to the downhole device; after receiving the signal, the downhole device sends a response signal to the control device; and the control device performs a logical analysis of the time from sending the signal to receiving the response signal.

[0010] It should be noted that the terms "triggering signal"and "latency adjusted signal"refer to different aspects of the same signal. The term "triggering signal"is used when referring to the purpose of the signal. The term "latency adjusted signal"is used when referring to the timing of the signal. In general these terms refer to a signal that has

been adjusted for latency and is intended to trigger an action of a downhole device.

[0011] It should also be noted that the term "latency"is intended to have a relatively broad meaning. "Computational latency"refers to the amount of time from when an instruction is received until it has been processed (e.g. the time elapsed between receiving a request for information and transmitting said information)."Transmission latency" refers to the amount of time it takes for an electrical pulse to travel between two devices over a downhole network integrated into a downhole tool string. "Total signal latency" refers to a combination of computational latency and transmission latency. Generally, the term "latency"refers to total signal latency.

[0012] Preferably hardware is designed such that the time between the downhole device receiving the signal and sending the response signal is a known constant. The method of determining latency may be done multiple times, and the results may be analyzed to find an average latency. In the preferred embodiment the control device is a computer. The control device may comprise a connection to a local area network. The control device may comprise a clock source. The clock source may be selected from the

group consisting of at least one crystal, at least one transistor, at least one oscillator, at least one RC circuit, at least one LC circuit, and at least one RLC circuit.

[0013] In the preferred embodiment the control device communicates with multiple downhole devices via one electrically conducting media, the latency between each device and the control device is determined by the control device, and the control device sends triggering signals to each device. In an alternate embodiment the control device communicates with the downhole devices via separate electrically conducting medium.

[0014] In the preferred embodiment each downhole device comprises a local clock source. The clock source may be selected from the group consisting of at least one crystal, at least one transistor, at least one oscillator, at least one RC circuit, at least one LC circuit, and at least one RLC circuit. The clock source of each downhole device may be synchronized to the clock source of the control device. In the preferred embodiment, one triggering signal is sent to all the downhole devices, with a portion of the signal designated for and used by each device. In an alternate embodiment, separate triggering signals are sent to each downhole device.

[0015] Also disclosed is a downhole device that performs the action at the moment the triggering signal is received. Alternately, the downhole device performs the action some delay after receiving the signal, where the delay may be relative to a local clock source. Disclosed is a triggering signal which contains instructions to the downhole devices to trigger at a specified time of day.

[0016] Preferably, the downhole devices perform actions after a delay relative to a local clock source. The downhole devices may perform different actions. The event may be performed by the control device, a clock, surface equipment, or another downhole device. In some embodiments, the downhole devices are selected from the group consisting of sensors, motors, jars, seismic sources, seismic receivers, steering elements, hammers, and repeaters. The actions may be selected from the group consisting of data acquisition, mechanical operations and electrical operations. The mechanical operations may be the actuation of a hammer, a jar, or another seismic source. The electrical operations may be the recording of data, the start of an electrical motor, or the initiation of a repeater. An example of the synchronous triggering of multiple devices may be a seismic source that is triggered synchronously with

the recording of data from a number of seismic receivers. The time between the beginning of the recording and the reception of seismic energy may then be analyzed to determine subterranean formations. In an alternate embodiment, the intermediate downhole devices perform actions after a delay relative to a local clock source, and the final downhole device performs an action at the moment the triggering signal is received.

## BRIEF DESCRIPTION OF DRAWINGS

[0017] Fig. 1 is a block diagram of an embodiment of an integrated downhole network in a downhole tool string.

[0018] Fig. 2 is a block diagram of an embodiment of a control device in communication with two downhole devices.

[0019] Fig. 3 is a flow chart of an embodiment of a method for triggering an action.

[0020] Fig. 4 is a block diagram of an embodiment of a control device in communication with one downhole device.

[0021] Fig. 5 is a block diagram of an embodiment of a control device in communication with downhole devices.

[0022] Fig. 6 is a block diagram of an embodiment of a signal configuration.

[0023] Fig. 7 is a block diagram of an embodiment of a signal configuration.

## Detailed Description

[0024] Fig. 1 shows an embodiment of the integrated downhole network 60 in a downhole tool string 62 with multiple downhole devices 61. The control device 59 is connected 75 to a downhole network 60 integrated into a downhole tool string 62. Total signal latency of a signal 66 traveling between the control device 59 and each downhole device 61 connected to the downhole network 60 may vary based on the transmission latency of the downhole network 60. The total signal latency may be affected by electrical connectors in the network 60, the time for devices 61 to process signals, the number of intermediate repeaters in the network 60, or the length of the signal 66. Total signal latencies between the control device 59 and each downhole device 61 are determined by the control device 59. The total signal latency to each downhole device 61 is determined by the control device 59 sending to each downhole device 61 a first signal 66. After receiving the first signal 66, each downhole device 61 sends to the control device 59 a response signal 67. The control device 59 measures the time between sending the first signal 66 and receiving the response signal 67. The control device 59 performs logical analysis on the measurement to determine latency.

The control device 59 then sends a latency adjusted signal 68 to each downhole device 61. Each downhole device 61 triggers an action synchronized to an event which may be performed by the control device 59, a clock 63, surface equipment 65, or another downhole device 61. The clock 63 may be part of the control device 59. Alternately, the clock 63 may be external, such as a GPS clock or a system clock. The clock 63 may be synchronized to a GPS clock. Generally, the integrated downhole network 60 comprises one or more components integrated into a downhole tool string 62. Preferably the components comprise first and second communication elements proximate both ends of the component and an electrical conductor which connects the elements. The communication elements may be made of magnetically conductive and electrically insulating material, such as ferrite. Alternatively, the communication elements may comprise electrical contacts.

[0025] Fig. 2 represents our preferred embodiment. The preferred embodiment has a control device 31. This control device 31 is preferably a computer. The control device 31 may comprise a connection to a local area network. The control device 31 is preferably in communication with multiple downhole devices 32a, 32b via one electrically

conducting media 33. The nodes 64 shown here and in the following drawings may be as complex as discussed in U.S. Patent Application Serial No. 60/481225, entitled "Distributed Downhole Drilling Network," and filed August 13, 2003 in the name of David Hall, et. al. The nodes 64 may alternately be as simple as a network interface modem or control logic for interfacing with a network.

[0026] The total signal latencies 34, 35 between the control device 31 and individual downhole devices 32a, 32b may be determined by the control device 31. In the preferred embodiment, the latencies 34, 35 are determined by the control device 31 sending to the downhole device 32a, 32b a first signal 36, and after receiving the first signal 36, each downhole device 32a, 32b sends to the control device 31 a response signal 37. Preferably, the control device 31 measures the time between sending the first signal 36 and receiving the response signal 37 to determine a time required. This measurement may be obtained multiple times, and an average may be taken to determine an average time required. Preferably, hardware in each downhole device 32a, 32b is designed such that the computational latency 38 between the downhole device 32 receiving the first signal 36 and sending the response signal

37 is a known constant.

[0027] The control device 31 may perform logical analysis on the measurement to determine latency. The control device 31 may subtract the computational latency 38 between the downhole devices 32a, 32b receiving the first signal 36 and sending the response signal 37 from the time required or the average time required. The control device may also divide time required or average time required by two to get a time for the first signal 36 to reach the downhole device 32a, 32b. The control device 31 then sends a latency adjusted signal 39 to each downhole device 32a, 32b.

[0028] Preferably each downhole device 32a, 32b triggers an action after some delay 40, 41 relative to a local clock source 42, 43 and synchronously with another event which may be performed by the control device 31, a clock 76, surface equipment 65 (in Fig. 1), or another downhole device 32a, 32b. The downhole devices 32a, 32b may be selected from the group consisting of sensors, motors, jars, seismic sources, seismic receivers, steering elements, hammers, and repeaters. The local clock source 42, 43 may be synchronized to the clock source 76 of the control device 31. The clock sources 42, 43, 76 may be selected

from the group consisting of at least one crystal, at least one transistor, at least one oscillator, at least one RC circuit, at least one LC circuit, and at least one RLC circuit. The local clock source 42, 43 may be synchronized to the clock source 76 of the control device 31. The actions may be selected from the group consisting of data acquisition, mechanical operations and electrical operations. The mechanical operations may be the actuation of a hammer, a jar, or another seismic source. The electrical operations may be the recording of data, the start of an electrical motor, or the initiation of a repeater. An example of the synchronous triggering of multiple devices may be a seismic source that is triggered synchronously with the recording of data from a number of seismic receivers. The time between the beginning of the recording and the reception of seismic energy may then be analyzed to determine subterranean formations. The downhole devices 32a, 32b may perform different actions. The actions may be performed at a specified time of day. Alternatively, some devices may have no delay 41, 40, but will trigger as soon as the signal reaches the device 41, 40.

[0029] For example, the delays 40 of the other downhole devices 32a may be adjusted to trigger at the moment the last

downhole device 32b receives the latency adjusted signal 39, and the last downhole device 32b may have no delay 41 and trigger at the moment it receives the latency adjusted signal 39. This may result in all the downhole devices 32a, 32b triggering at the same moment, which may be synchronized with another event.

[0030] Fig. 3 illustrates an embodiment of a method 77 for triggering an action of a down-hole device 45 synchronized to an event, and references figure 4 and figure 2. Step 69 comprises a control device 31 sending a first signal 36 to a down-hole device 45. Step 70 after receiving the first signal 36, the downhole device 45 sends a response signal 37 to the control device 31. Preferably, hardware is designed so that the time 38 between the downhole device receiving the first signal 36 and sending the response signal 37 is a known constant. Step 71 determines the time between the control device 31 sending the first signal 36 and receiving the response signal 37. Step 72 determines the time for the first signal 36 to reach the downhole device 45 using the time measured in step 71. The time for the first signal 36 to reach the downhole device 45 is preferably computed using logical analysis. The logical analysis may be performed by assuming the total

signal latency from the control device 31 to the downhole device 45 is equal to the total signal latency from the downhole device 45 to the control device 31 and dividing the time measured by two. In step 73 the control device 31 sends a latency adjusted signal 39 for triggering an action. In the final step 74 the down-hole device 45 receives the latency adjusted signal 39 and performs the action. In the embodiment shown in figure 4, the action is performed at the moment the latency adjusted signal 39 is received. Preferably, the action is performed after a specified delay 40, 41 relative to a local clock source. The delay 40, 41 may be different for each downhole device 45, 32a, 32b. The local clock source may be synchronized to the clock source 76 of the control device 31. Alternately, the action is performed at a specified time of day.

[0031] Fig. 4 shows an alternate embodiment. In this embodiment, a control device 31 is in communication with one downhole device 45 via one electrically conducting media 33. The time 44 required for a signal 36 to travel between the control device 31 and the downhole device 45 is determined by the control device 31. The control device 31 then sends a latency adjusted signal 39 to the downhole device 45. The downhole device 45 triggers the action at

the moment it receives the latency adjusted signal 39. The downhole device may also comprise a local clock source, and may trigger the action after a delay, or at a specific time of day. The local clock source may be synchronized to the clock source 76 of the control device 31.

[0032] Fig. 5 shows an embodiment of a control device 31 in communication with multiple downhole devices 46, 47 via multiple electrically conducting medium 48, 49 and may be in communication via nodes 64. The times 50, 51 required for a signal to travel between the control device 31 and the downhole devices 46, 47 are determined by the control device 31. The control device 31 then sends separate latency adjusted signals 52, 53 to the downhole device 46, 47. The latency adjusted signals 52, 53 may be sent simultaneously or at different moments in time. The downhole devices 46, 47 trigger the actions at the moment the adjusted signal 52, 53 is received. In this embodiment, the adjusted signal 52, 53 is sent to each downhole device 46, 47 so that the adjusted signal 52, 53 is received by each downhole device 46, 47 simultaneously, and may occur synchronously with another event. The downhole devices 46, 47 may also comprise a local clock source and may trigger after a delay, or at a specific

time of day. The local clock source may be synchronized to the clock source 76 of the control device 31.

[0033] Fig. 6 shows an embodiment of a configuration of the latency adjusted signal 39 for the triggering of two downhole devices, and references figure 2. In this embodiment, the signal 54 is a packet of information. The packet 54 comprises a field 57, 58 for each downhole device 32a, 32b. Each downhole device 32a, 32b receives the same packet 54, and reads the designated field 57, 58. The number of fields may be equal to the number of downhole devices.

[0034] Fig. 7 shows an embodiment of a configuration of the adjusted signal 39 for the triggering of two downhole devices, and references figure 2. Separate signals 55, 56 are sent to each downhole device 32a, 32b. For a network that communicates via one electrically conducting media 33 such as in Fig. 2, the signals may be sent consecutively, and may not overlap in time. Interference between the two signals may result if the second signal is started before the first signal has ended. For a network that communicates via multiple electrically conducting media 48, 49 such as in Fig, 5, the signals may be sent simultaneously.

[0035] Whereas the present invention has been described in par-

ticular relation to the drawings attached hereto, it should be understood that other and further modifications apart from those shown or suggested herein, may be made within the scope and spirit of the present invention.